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A SYSTEM OF MATHEMATICAL MODELS FOR WATER QUALITY MANAGEMENT

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A SYSTEM OF MATHEMATICAL MODELS

FOR

WATER QUALITY MANAGEMENT*

Technical Report 51

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PREFACE

Requests for the following paper have been numerous enough to warrant reissue as a technical report. In order to bring the paper up to date and to inform the reader of additional developments, a short addendum has been attached.

The author wishes to acknowledge the support and cooperation of the personnel of EPA, Region III, in the continuing development of the model system here described. At the present time, the model system, now called the CMS (Comprehensive Model System) is being applied to the Chesapeake Bay and its tributaries in a farsighted effort to aid in protecting the Chesapeake from the everpresent threat of man's uncontrolled activities.

INTRODUCTION

A mathematical model can be defined as the representation of a physical process or set of processes by their governing natural laws as expressed by the abstractions of mathematics. In particular, hydraulic and water quality models deal with the representation of rivers and estuaries and their behavior under varying conditions of flow and input quality. The mathematics include the approximations and discretizations necessary for solutions by digital computer.

In recent years there has been a proliferation of digital programs in the water resources field. Most have been concerned with economics and evaluation of alternatives using linear programming and operations research. Some others dealt with the statistics of population growth and projection. After the initial flurry of activity, things became routine. Each major computer manufacturer has on line programs easily utilized by skilled or semi-skilled personnel. These packages will give economic analyses and optimizations without the need for detailed mathematical knowledge by the user. As a result, a highly sophisticated analysis can now be made by small firms and individuals at a very nominal cost.

The state of the modeling art presently permits no such ease in its application. Hydraulic and water quality models have historically been single purpose with little or no generality. The journals abound with reports of "newer" or "better" mathematical models of a specific river or river system. These programs or "models" are generally cumbersome and unintelligible to the non-specialist. Those models which have some general application frequently are not comprehensive enough to be of any great value.

The purpose of this paper is to review the basic equations involved in modeling hydraulic and water systems. A general method of model construction will be presented. In this way, a prospective user will have access to tools which may have previously been unapproachable.

Model Construction Principles

A properly formulated mathematical model should be able to reproduce past history. Given known input values of flow and quality, it should be able to duplicate any measured values within limits. The accuracy with which the model results compare with historical records is an indication of the model's reliability in projecting the future. The model's verification record is not, however, the only measure of its validity.

Most statistical and empirical methods are so formulated as to insure normal verification. This is because the past record was used as the basis for the equations and their coefficients. There is no assurance, however, that even minor changes in the physical situation will not cause very large errors in the predictions produced by such methods. The complexities of hydraulic and quality networks do not often lend themselves to such simplistic solutions.

In contrast to empirical methods, a really reliable model must be based on fundamental principles. Any assumptions or simplifications made must be consistent with the model's intended use. Particular attention must be paid to fundamentals in cases where inadequate or incorrect input data makes verification difficult. One method of checking models in locations where no historic data is available is to check it for another location. If the model is well constructed, one river is the same as another. Only the dimensions and inputs are different.

Hydraulic Models

Investigations of water quality problems cannot be made without an adequate knowledge of the flows and flow patterns in the body under question. The adequacy of the flow solutions is a primary factor in the final results.

Hydraulic situations may vary from an estuarine network to a simple fresh water stream. However, both systems obey the same natural laws.

Those laws will be presented here along with the assumptions and simplifications appropriate to each case.

The first restriction is that of considering only one dimensional flow in open channels. The governing equations are the equations of motion:

$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - K\, u|u| - g\frac{\partial h}{\partial x} \qquad (1)$$

$$K = \frac{gn^2}{2.208} R^{4/3}$$

and continuity:

$$\frac{\partial h}{\partial t} = -\frac{1}{B} \frac{\partial (uA)}{\partial x} \qquad (2)$$

where:

u is the velocity in the channel

X is the distance along the channel

A is the cross-sectional area of the channel

B is the channel width

h is the water surface elevation or stage

t is time

g is the acceleration due to gravity

K is the frictional resistance computed by the Manning equation (1a)

R is the hydraulic radius of the channel

n is Manning's "n"

Assumptions inherent in these equations are:

1. the wavelength is much longer than the channel depth.
2. wind stresses are negligible.
3. coriolis forces do not influence the flows.

Rewriting equation (1) in a form more convenient for digital methods gives the following set of basic equations:

$$\frac{\partial u}{\partial t} = \frac{u}{A}\frac{\partial A}{\partial t} - K\,u|u| + \left(\frac{u^2 B}{A} - g\right)\frac{\partial h}{\partial x} \qquad (3)$$

and

$$\frac{\partial h}{\partial t} = \frac{1}{B}\frac{\partial (uA)}{\partial x} \qquad (4)$$

These are the equations to be solved for the unsteady case in one-dimensional open channel flow.

By zeroing all the terms variable with time and assuming the hydraulic gradient $\frac{dh}{dx}$ is small compared with depth, the set of equations reduces to the Manning equation for velocity:

$$u = \frac{1.49\,R^{2/3}\left(\frac{\partial h}{\partial x}\right)^{1/2}}{n} \qquad (5)$$

and

$$\frac{1}{B}\frac{\partial (uA)}{\partial x} = 0 \qquad (6)$$

Discretization:

Digital computers can only handle finite quantities. They are not able to deal with the abstractions that accompany analytic solutions. Consequently, we must break our equations down into finite elements of time and space.

The equation (3), (4) for the unsteady case becomes:

$$\frac{\Delta u}{\Delta t} = \frac{u}{A}\frac{\Delta A}{\Delta t} - Ku|u| + \left(\frac{u^2 B}{A} - g\right)\frac{\Delta h}{L} \qquad (7)$$

and

$$\frac{\Delta h}{\Delta t} = \frac{\Sigma Au}{As} \qquad (8)$$

where:

L is the length of the channel

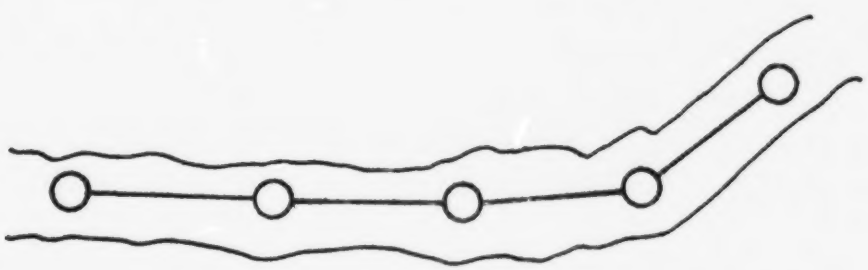
A_s is the surface area of a "junction"

In the discretization process, the concept of channel "lengths" and junction "surface areas" has been introduced. The method of breaking a body of water into finite elements of geometry most often determines the model's usefulness. A program which is tied internally to a certain locality will require major work in order to run another area. This accounts for the bulk of the many "new" models now is existence. To avoid following the same track, the method here presented uses the geometric data and configuration as input values.

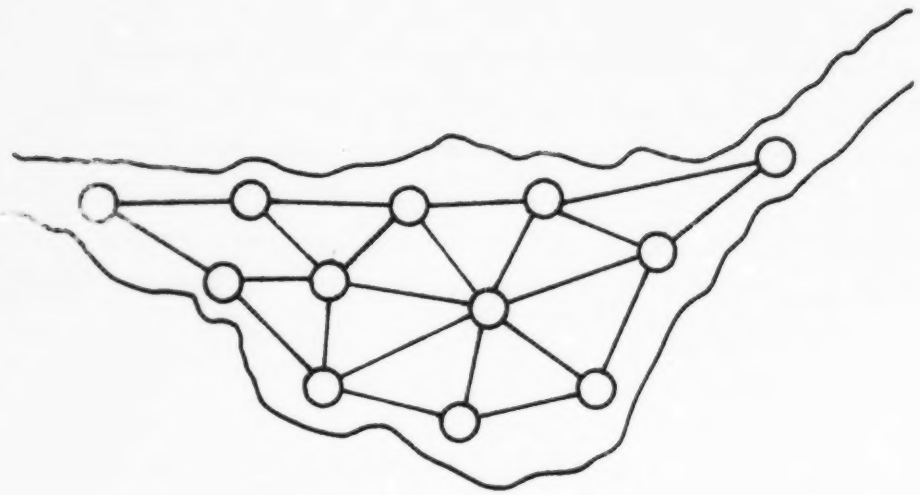
The segmenting process is best presented by means of the following guidelines:

1. Junctions are defined as the intersection of one or more channels.
2. The variables head (h) and surface area (A_s) are associated only with junctions.
3. Channels are used to connect two junctions.
4. The variables of velocity, flow, cross-sectional area, hydraulic radius, length, width, and frictional resistance are concerned only with channels.

The following figures illustrate the method for some typical examples:



SINGLE CHANNEL



OPEN BAY

These configurations can be compounded to cover all parts of the area. Channel lengths should not vary widely from one area to another. For reasons of computational stability, channel lengths in the network should not have a range greater than 5 times. That is, the longest channel should be less than 5 times the length of the shortest channel.

Applications of the equations to various physical cases:

Physical problems are composed of four types. The consist of steady or unsteady flow in single channels or interconnected networks.

Unsteady flow problems might result in estuaries or flood conditions in inland river systems. Flood conditions are not normally of importance in pollution problems, and no attempt will be made to describe them here. Estuarine problems deserve particular attention because of their complex nature.

Steady flow conditions are encountered most often in inland rivers and streams. There, flow problems are generally easy to solve. Certain cases of narrow channeled estuaries, where net flows are desired, can be treated as steady flow problems.

No distinction is made between single channel and interconnected channels in the unsteady case. The method of solution is the same.

Unsteady (tidal) flow solution:

The following data is required:

1. Junctions
    a. Junction number
    b. Beginning head (usually mean tide elevation) (ft.)
    c. Surface area (sq. ft.)
    d. Area slope (sq. ft. per ft.)
    e. Inflow to junction (cfs)
    f. Outflow from junction (cfs)
    g. Channel numbers entering junction

Note: e and f refer to discharges or extractions at a junction, not channel flows. Junction surface area is defined as one-half the sum of the surface areas of the channels entering the junction.

2. Channels
    a. Channel number
    b. Length (ft.)
    c. Width (ft.)
    d. Cross-sectional area (sq. ft.)
    e. Hydraulic radius (ft.)
    f. Manning's "n"
    g. Starting velocity (fps)
    h. Junction numbers at ends of channel

In addition, one junction is used as the driving point. At this point, the head will be computed at any time from a seven term Fourier series reduction of a known tidal cycle or cycles. This curve will be repeated over as many periods as desired.

As the program is operating, the errors in the initial conditions (starting heads and starting velocities) are damped out. After about one

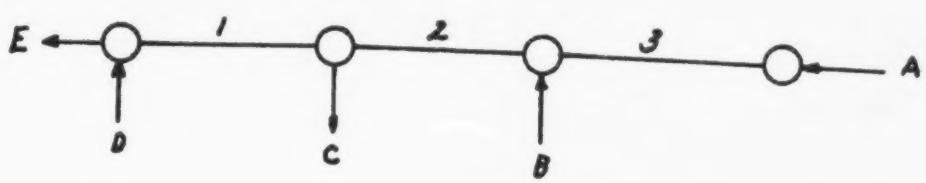
period, the program is actually simulating tidal action throughout the network.

Net flows are computed by averaging the flows over a complete period. As a check on the stabilized condition of the program, the sum of all the net flows and inputs or withdrawals at a junction should be zero.

Previously, the steady condition was derived as a special case of the unsteady problem. Indeed, the same program can be run with the specified head held constant over its period. There are, however, other methods which have been shown to be more economical.

The alternate solutions are divided into two categories. A simple flow balance is used in the case of a single channel, while a head-flow balance is used for interconnecting channels. The head-flow balance is sometimes called the "Hardy Cross" solution.

The flow balance is illustrated by the following diagram:



$E = A+B+D-C$

$Q_3 = A$

$Q_2 = Q_3 + B$

$Q_1 = Q_2 - C = D-E$

A negative Q_n represents a flow opposite in sign to that assumed.

The Hardy Cross method relies on the principle that the head losses around a loop composed of channels must sum to zero when the flows are balanced.

Returning to the equations (5) and (6):

$$u = \frac{1.49\, R^{2/3} \left(\frac{\Delta h}{L}\right)^{1/2}}{A}$$

and:

$$\frac{\Delta h}{\Delta t} = \frac{\Sigma Au}{A_s} = 0$$

rewriting to solve for $\Delta h = u^2 L \left(\frac{n^2}{2.208\, R^{4/3}}\right) = \frac{q^2 L}{A^2} \left(\frac{n^2}{2.208\, R^{4/3}}\right)$

where $q = Au$

Around a loop:

$$\Sigma \Delta h = \Sigma \frac{L}{A^2} \left(\frac{n^2}{2.208\, R^{4/3}}\right) q^2$$

If $\Sigma \Delta h$ is not zero, a correction to the flows in the channels comprising that loop is computer as:

$$\Delta q = \frac{\Sigma \Delta h}{\Sigma \frac{\Delta h}{q}} = \frac{\Sigma \frac{L}{A^2} \left(\frac{n^2}{2.208\, R^{4/3}}\right) q^2}{\Sigma \frac{L}{A^2} \left(\frac{n^2}{2.208\, R^{4/3}}\right) q} \qquad (9)$$

Each loop is computed separately and the corrections are applied to the channels. Channels which are common to two loops will receive two corrections. The procedure continues until the corrections are less than some specified value.

The data requirements for the Hardy Cross solution are essentially the same as for the unsteady case with the addition of information concerning the loops. The number of loops, the junction numbers comprising each loop and assumed directions of flow in each channel are needed.

As stated before, the steady type of solutions can be used in estuaries if we are interested in the distribution of net flows. There are qualifications to this statement which should be pointed out. The use of the flow balance or the head loss balance in open bays, is not valid. There are two dimensional circulation patterns in these bays which are important in distributing pollutants. These patterns would not show up in a single channel representation.

If we divide the bay into a number of interconnected channels, the pattern given by the Hardy Cross solution will, in general, be incorrect. The net flows given by the unsteady flow solution are much more reliable in these cases.

Uses of the hydraulic models:

The primary uses of the hydraulic models are as generators of flow values for compatible quality solutions. The models are quite capable of standing alone as tools for investigation of hydraulic improvements.

The unsteady flow model is particularly useful in showing the effects of dredging, filling or restricting channels in estuaries. The velocities computed during a tidal cycle are also of use in sedimentation studies and the like.

In short, the potential of these programs is limited only by the imagi nation and judgement of the user.

Quality Models

Once the flow patterns have been determined, the study of pollutant distributions can be made. Studies of quality in a body of water are normally concerned with either conservative (salinity, TDS) or non-conservative (Dissolved oxygen, BOD) substances. Either a steady state or time variable solution may be desired.

The use of the basic equations will be based on the general properties of the segmenting procedure used by the hydraulic models.

Again, assuming one dimensional distribution along a completely mixed channel, the mass balance of the channel can be written for a conservative substance as:

$$\frac{\partial c}{\partial t} = E \frac{\partial^2 c}{\partial x^2} - u \frac{\partial c}{\partial x} \qquad (10)$$

where:

E is the eddy diffusion coefficient

C is the concentration in the channel at any point, X

Integrating along X and multiplying by A (the area of the channel) gives:

$$\frac{\partial m}{\partial t} = EA \frac{\partial \bar{c}}{\partial x} - q \bar{c} \qquad (11)$$

where:

$\bar{C}$ is the average concentration along the channel

m is the total mass in the channel.

Writing the equation in discrete form:

$$\frac{\Delta M}{\Delta t} = EA \frac{\Delta \bar{c}}{L} - q\bar{c} \qquad (12)$$

where L is the length of the channel. By summing the channels around a junction, we can define junction masses. Thus, at a <u>junction</u>:

$$\frac{\Delta M}{\Delta t} = \Sigma EA \frac{\Delta \bar{c}}{L} - \Sigma q\bar{c}$$

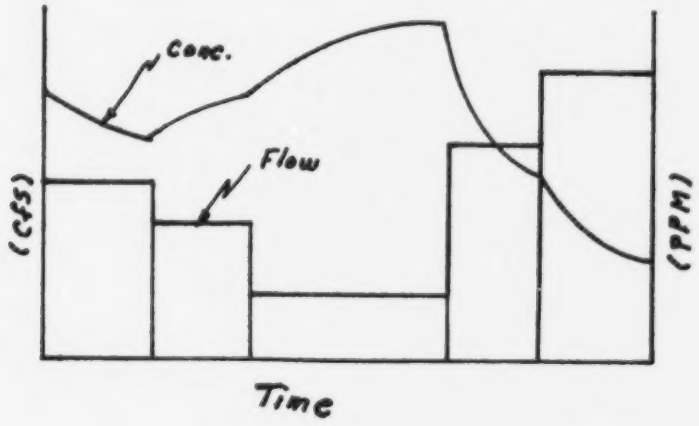
Adding terms for the addition of material through discharges and the extraction of water yields the following equation:

$$\frac{\Delta M}{\Delta t} = \Sigma EA \frac{\Delta \bar{c}}{L} - \Sigma q\bar{c} + \Sigma c_{in} Q_{in} - \frac{M}{V} \Sigma Q_{out} \qquad (13)$$

The above equation can be used to compute junction qualities with either the unsteady or steady flows computed by the hydraulic models.

It is appropriate here to ask how steady flows can be used to compute nonsteady state qualities. We may answer by noting that a system's hydraulic response to a change in input flows is much faster than the quality reaction. For example, the time required to flush wastes out of a stream is much larger than the time required to reach steady flow in the same stream.

The term "quasi-steady state" is used to describe the situation where flow is changing in stairstep fashion:



while quality is computed as a smooth curve. This situation is common in estuaries subject to seasonal changes in fresh water inflow. The models used by the Delaware study were based on this type of arrangement.

When using the results of the unsteady hydraulic model for short periods, a simplification is made to equation (13). The dispersion term is dropped since the time intervals are very small (i.e., 6 minutes to 1 hour). The assumption is that the advective term ($\Sigma q\bar{c}$) is the predominant factor. Hence:

$$\frac{\Delta M}{\Delta t} = \Sigma q\bar{c} + \Sigma C_{in} Q_{in} - \frac{M}{V} \Sigma Q_{out} \qquad (14)$$

This may be called the unsteady flow-unsteady quality equation.

The simplest case to solve and probably the most difficult to attain in nature is the steady state. Equation (13) equated to zero and solved. Obviously, steady flow model or the steady flow models are considered. The equation is:

$$\Sigma EA \frac{\Delta \bar{c}}{L} - \Sigma q\bar{c} + \Sigma C_{in} Q_{in} - \frac{M}{V} \Sigma Q_{out} = 0 \qquad (15)$$

The solution to a set of these equations can be done iteratively or by a matrix inversion. Iteration is used for this network scheme presented. Inversion requires prior knowledge of such things as flow direction and amount.

Values of the dispersion coefficient E have a wide range. Most fresh water streams have a negligible value of dispersion, while in estuaries, dispersion may be the most important parameter to be considered.

Dispersion is a combination of the effects of eddy diffusion and the motion of the water under tidal action. The units of E are length squared per time (sq. ft./sec). Much work has been and is presently being done on determining dispersion coefficients. A combination of judgement, experience and adjustment are the best means of obtaining working values of E at the present time.

Non-Conservative models:

Typical non-conservative materials are BOD and organic nitrogen. They may be modeled using equation (13) with the added time dependent factor:

$$\frac{\Delta M}{\Delta t} = \Sigma EA \frac{\Delta \bar{c}}{L} - \Sigma q\bar{c} + \Sigma C_{in} Q_{in} - \frac{M}{V} \Sigma Q_{out} + K \frac{M}{V} \qquad (16)$$

where K is a coefficient of decay.

Dissolved oxygen may be modeled in much the same way. However, the BOD concentration must be computed simultaneously. Calling C_B the BOD conentration and C_D the dissolved oxygen deficit:

$$\frac{\Delta M_D}{\Delta t} = \Sigma EA \frac{\Delta \bar{C}_D}{L} - \Sigma q \bar{C}_D + \Sigma C_{D_{in}} Q_{in} - \frac{M_D}{V} \Sigma Q_{out} + K_2 C_D - K_1 C_B$$

where: K_1 is the BOD decay rate

K_2 is the coefficient of reaeration

In some cases it may be worthwhile to consider other sources and sinks of BOD and oxgyen such as:

1) Plankton photosynthesis and respiration
2) Removal of oxygen by bottom deposits
3) Removal of BOD by sedimentation

However, for most applications, these factors are not included.

Small modifications in the meaning or form of the K's can enable the user to solve a wide variety of problems. Virtually any measurable quality parameter can be distributed and traced by these models.

Model verification:

The verification procedure is one of the most important steps in any modeling activity. It is here that errors in the input data or selection of the model will show up.

Historical records of flow and quality in the system are selected according to the following criteria:

1) Availability of record and corresponding input values.
2) Accuracy of data.
3) Length of record.
4) Variability of hydrologic conditions.

Obviously, the accuracy of historical inputs to the program will have a large effect on the ac uracy of the verifications. In many cases, water quality is monitored to the extreme while waste water inflows are not well known. Similarly, many estuarine systems have an inadequate knowledge of the fresh water inflow. In these situations, the validity of the input estimates as well as the model results are being tested.

The type of model used has a great deal to do with the selection of historic record. For example, the unsteady flow-unsteady quality model requires values of quality measured at very short intervals. Conversely, the quasi-steady quality model should be checked over weekly or monthly intervals in the record.

Verification of the steady-state model requires a more devious path. Here, the quasi-steady model must be verified and run under constant conditions for a long period of time. Then the steady-state model is run under the same input conditions and compared to the quasi-steady model. The economy with which the steady-state model operates often makes such a roundabout process worthwhile.

In all models, well-defined trends in the historic record must be reproduced. Some differences in magnitude between the model results and the record can be expected, but the general shape of the two curves should always correspond.

A variety of hydrologic conditions should be run. Wet, dry, and average conditions will show the ability of the model to correctly respond. Again, special emphasis should be made on conditions which approximate the model's intended uses.

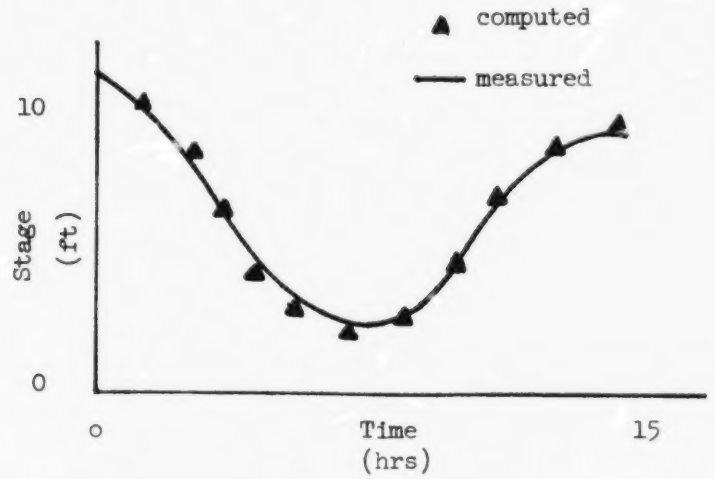
Model reliability:

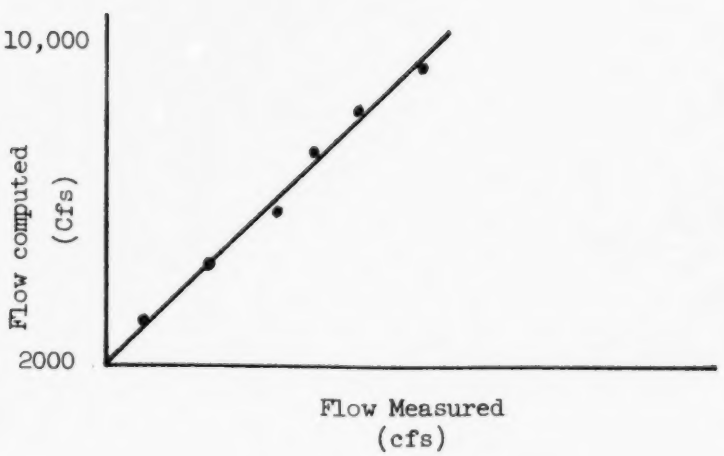
A system of models and modeling principles has been presented. We now turn to the results of such a system and examine their worth.

These models are meant to provide management with the means of evaluating alternatives of action. They are not meant to give precise results from specific inputs. The precision that can be estimated in prediction is reflected in the verification process. Differences between one input condition and another are of more use than an absolute value for either case.

For example, consider the question of what effect a paper mill's discharge has had or will have on a particular stream. The models will not give the resulting D. O. profile as accurately as they will give the change in the D. O. profile. Similarly, the models applied to estuarine problems have proven useful in determining the effects on salinity of reducing fresh water inflow. In essence, the models act much like a scale. The absolute weights registered are not as reliable or as important as the differences recorded from one time to the next.

Models based on the methods presented here have reproduced history with differences of the order of magnitude from $\pm$ 5 percent to $\pm$ 25 percent. The hydraulic models were the most successful. Typical comparisons are shown in the following figures:

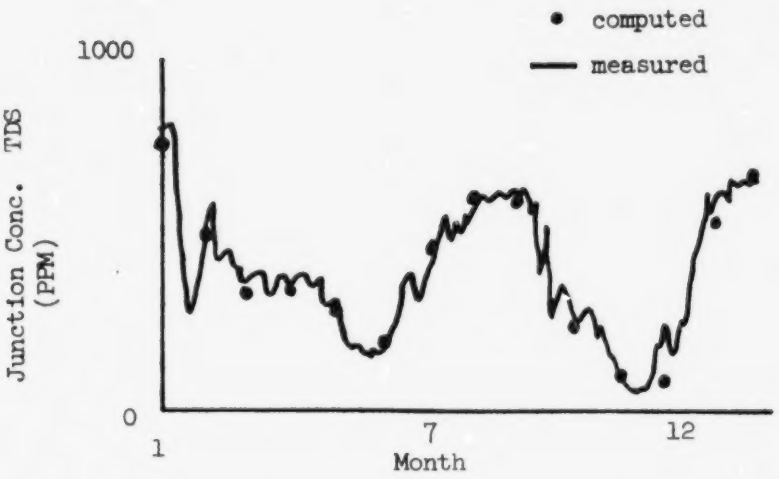


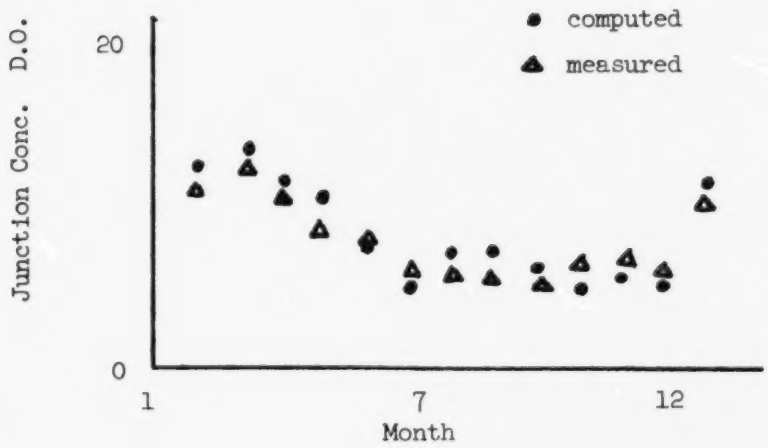


Unsteady Hydraulic Model

(Sacramento-San Joaquin Delta)

(1964-5 data)

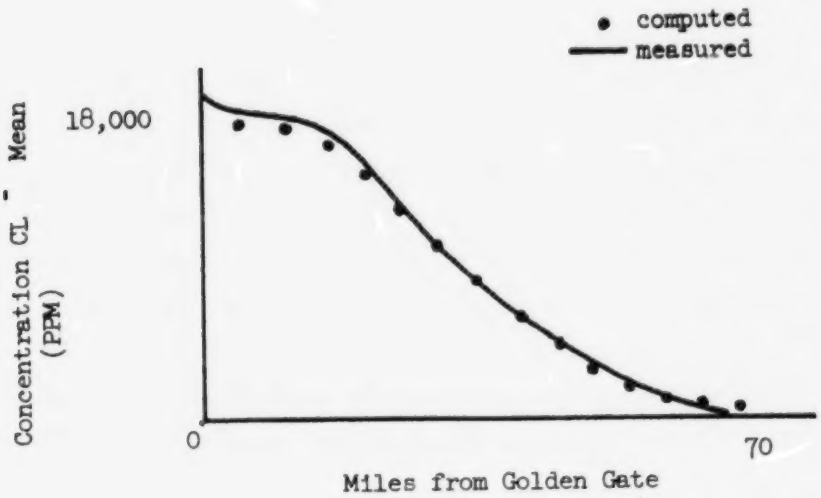


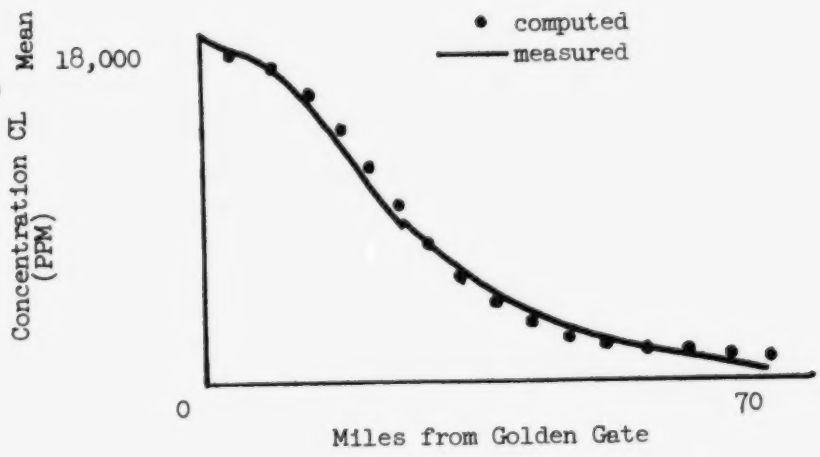


Quasi-steady Quality Model

(Sacramento-San Joaquin Delta)

(1961 data)





Unsteady Quality Model

(San Francisco-Bay Delta)

(1959 data)

SUMMARY

Properly formulated mathematical models can serve as valuable tools for the evaluation of man's actions on the hydraulic and water quality environment. At a time when many stream and estuarine systems are in critical condition, management needs methods which can show the effects of projects beforehand. The models presented here should aid in avoiding costly and time consuming mistakes in the evaluation of alternatives.

Virtually any hydraulic distribution problem in the water pollution control field can be solved with these hydraulic models. The results of the models have exhibited a high degree of accuracy.

The quality models are primarily designed to compute the effects of changing flow and point loadings on the system. Much must be done to enable these models to compute the effects of biological actions. Such parameters as photosynthesis and respiration are not adequately defined as yet. Perhaps the availability of these models will stimulate useful formulations of the more important biological reactions.

Hopefully, the range of the programs and the simplicity of their operation will result in more people using such methods.

Data Requirements and Definitions

Tidal information: Coeficients of a seven term sine and cosine series of the form:

$H_t = A \sin(wt) + B\sin(2wt) + c\sin(3wt) + D\cos(wt) + E\cos(2wt) + F\cos(3wt)$ and the period (in hours) of w.

Geometric data:

For junctions:
- Starting head (ft)
- Surface area (ft^2)
- Area slope (ft^2/ft)
- Discharge into junction (cfs)
- Discharge from junction (cfs)

For channels:
- Length (ft)
- Width (ft)
- Area (ft^2)
- Hydraulic radius (ft)
- Manning's "n"
- Starting velocity (ft/sec)

Network data:

For junctions:
- junction number
- channel numbers entering the junction

For channels:
- channel number
- junction numbers at each end of the channel

Loop information:
- A sequence of junctions for estimating flows.
- Total number of loops in the network
- Junction numbers defining each loop. The sequence defines the "positive" direction of flow

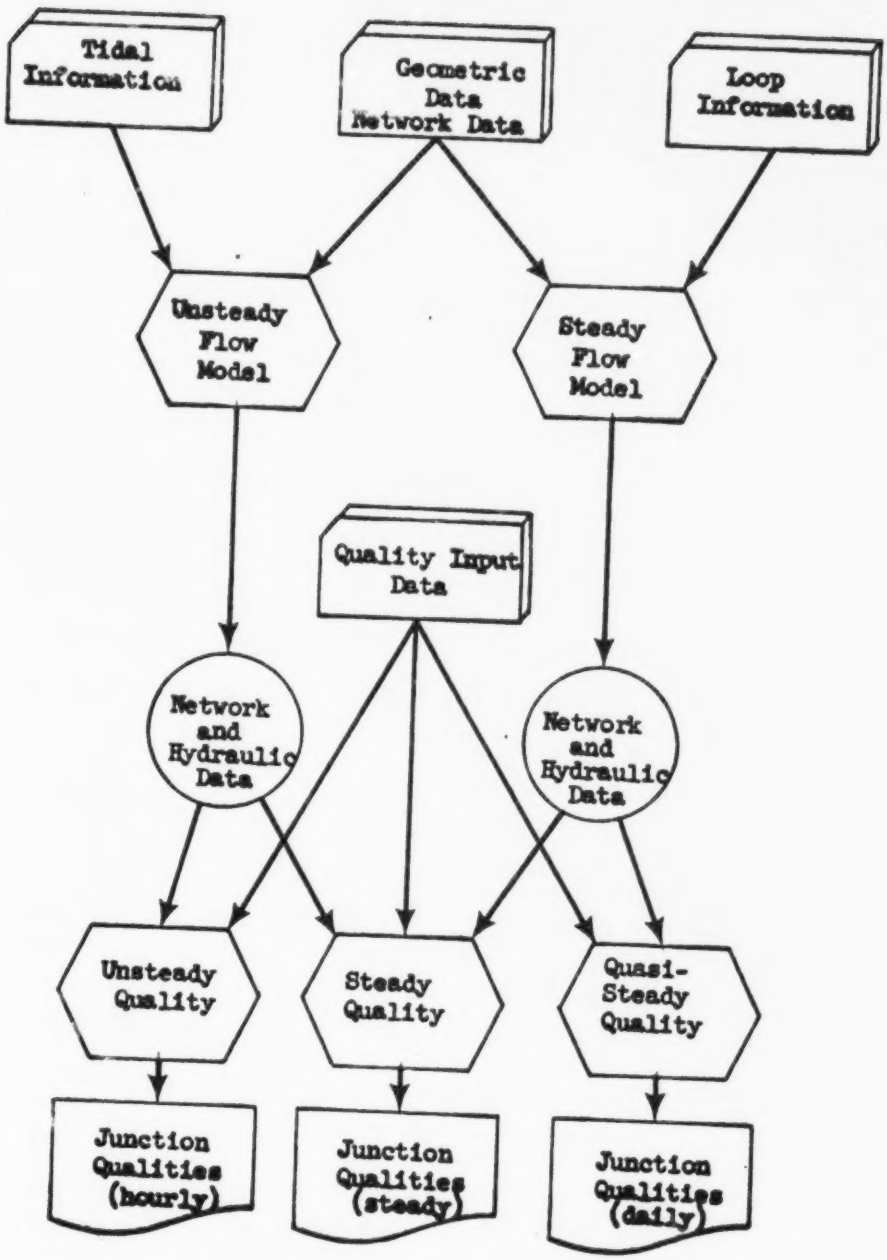
Quality Input data:

For junctions:
- Concentration of pollutant discharge (PPM)
- Starting concentration (PPM)
- Pollutant decay rate (PPM/day)
- Photosynthesis and respiration rates (PPM/day)

For channels: Dispersion constant (ft^2/sec)

General constant: water temperature (^oF)

Information Flow
Comprehensive Modeling System



ADDENDUM

Since the original paper was presented, several needed generalizations have been made to the model system. Also, geometrical modifications have given rise to new programs in the system. Modifications to the existing system will be considered first.

Unsteady Flow Program:

Equation (1) has be rederived to reflect the effect of sloping bottoms for the channels. The new equation is essentially the equation of Barre St. Venant or

$$\frac{\partial u}{\partial t} = - u\frac{\partial u}{\partial x} - K\, u|u| - gs - g\frac{\partial h}{\partial x} \qquad (1\text{-A})$$

where s is the channel bottom slope in ft/ft. The term s is computed as the difference in the depths at the junctions at each end of the channel divided by the channel length.

Tests of the two methods have indicated rather significant differences in flow patterns in open bags with irregular bottoms. Virtually no changes were observed in single channel type estuaries.

Unsteady Quality and Quasi Steady Quality Programs:

Experiences by the author and others indicated the need to rethink the meaning of Equation (11). The term $\bar{c}$ (the average concentration) and the term m (the mass in the channel) have been redefined to mean the concentration of material crossing the junction interface and the mass in the junction.

This is a radical if subtle change in thinking. Essentially it eliminates channels as a means of conveying material in the quality programs.

Experimentation has determined that careful attention to the geometry setup and more strict adherence to the Courant condition eliminates the instability which used to plague the models in certain cases. Accuracy and response times are greatly improved.

Close comparisons between the Steady Quality Program and the unsteady programs (run to steady state) are now possible.

Geometrical Restrictions and New Programs:

By restricting the network configuration to that of a single channel system, a time savings of an order of magnitude were made. Two new programs AUTOS and AUTOU are now operational. Their functions are the same as the Steady State and Quasi State Programs. The input is, however, much simpler and more flexible. The network is variable from run to run with very little setup work required. The two new programs maintain the same high technical level as their "big brothers." Their simplicity of operation and their reliability will make their use more common in planning types of functions.

Expansions to the Channel-Junction Technique:

Much has been done and is being done to define biological rates of growth and decay. A complex system of interactive differential equations has been derived with the channel-junction approach in mind. Test runs on an idealized system indicate that a high degree of success is possible. An ecological model has been proposed, and more work is planned along these lines.

A multi-layered hydraulic model is also under investigation. This program (called MULTIQ) would reflect the effects of variable densities, variable wind stresses, and variable atmospheric pressures on the three-dimensional circulation patterns in large estuaries and lakes. This program when fully developed, will contribute much toward the solution of the intricate flow patterns of stratified estuaries under the influence of buoyant discharges.

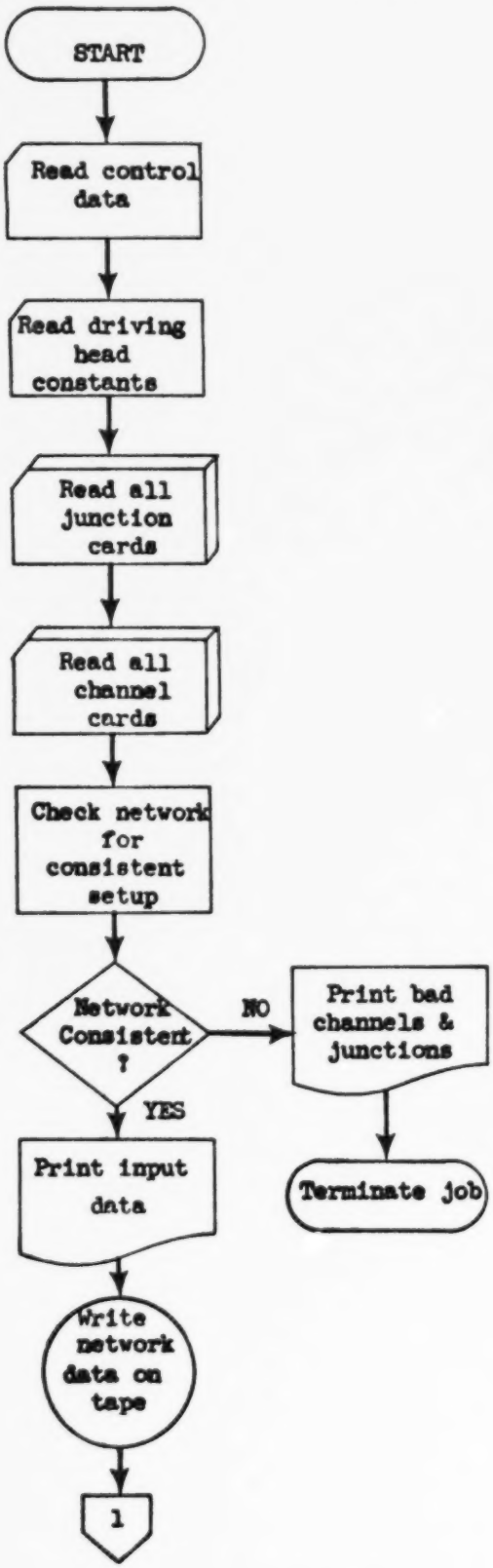
The work is presently being carried out by the Engineering Development Section, Annapolis Field Office, Environmental Protection Agency, Region III, Annapolis, Maryland.

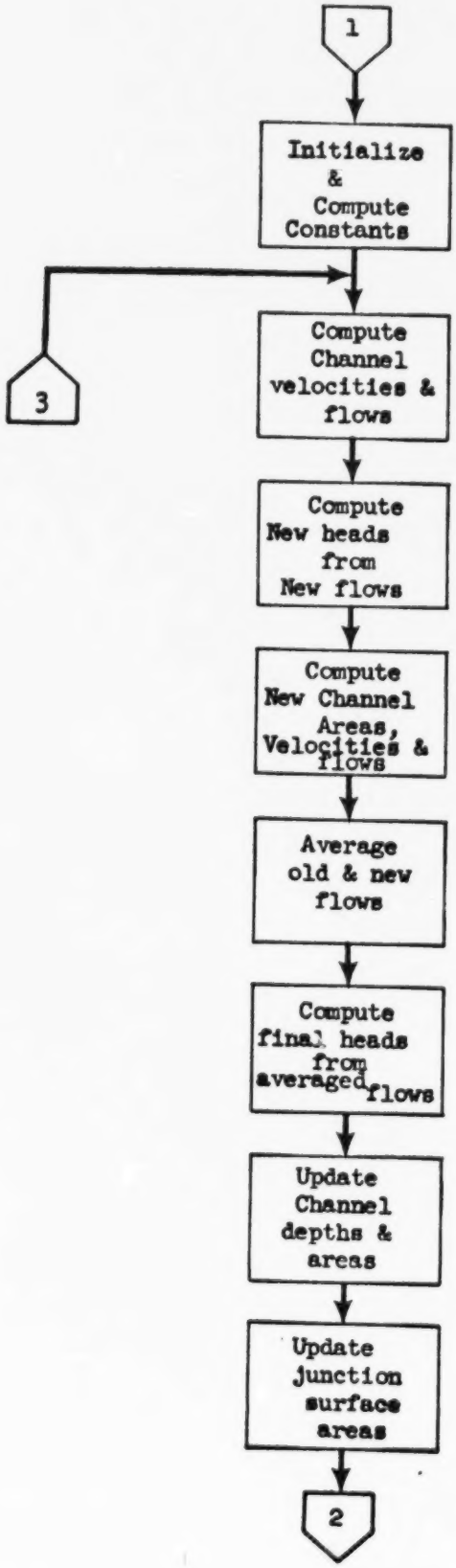
Interested parties are invited to write directly for more information.

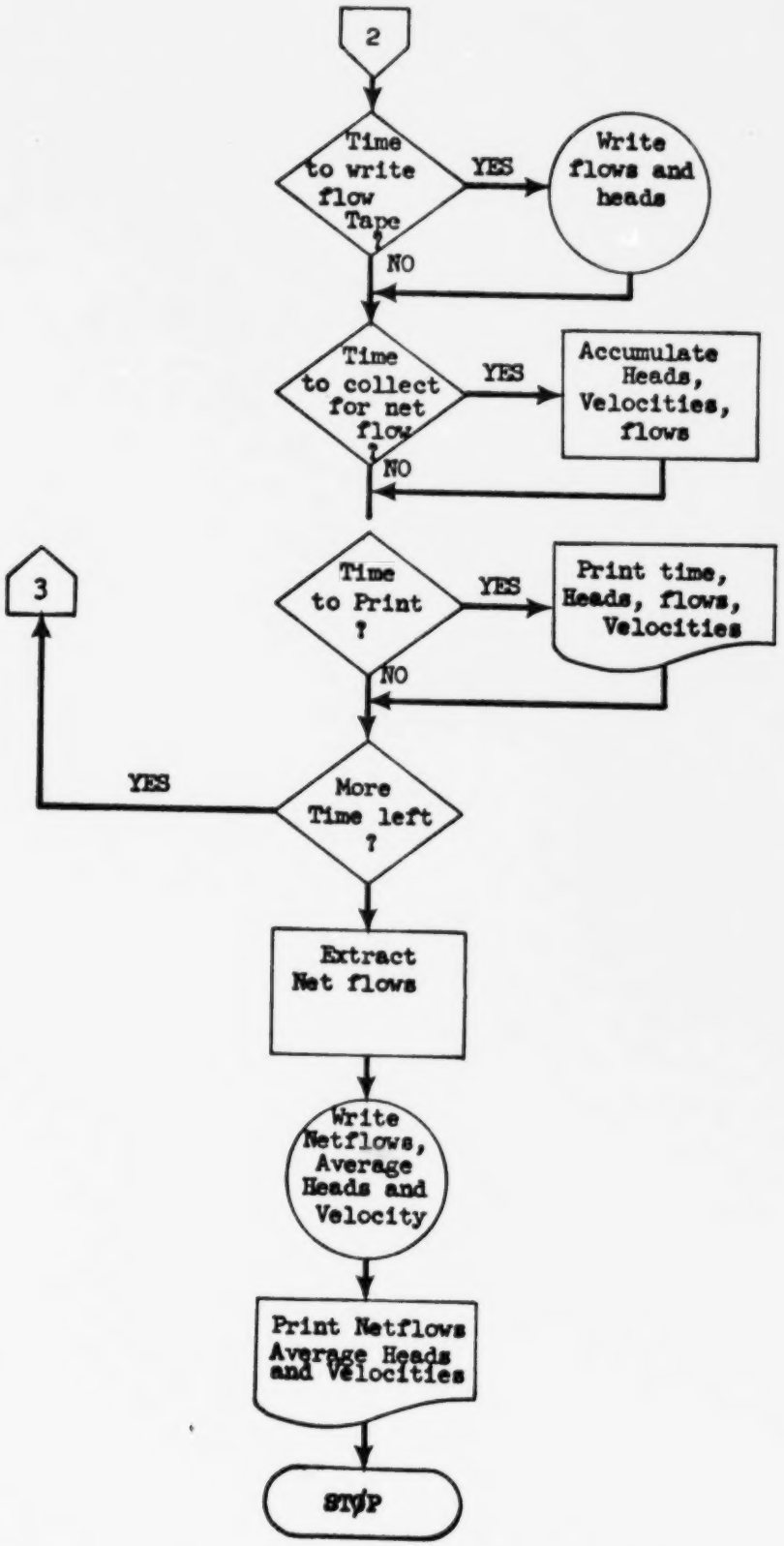
APPENDIX

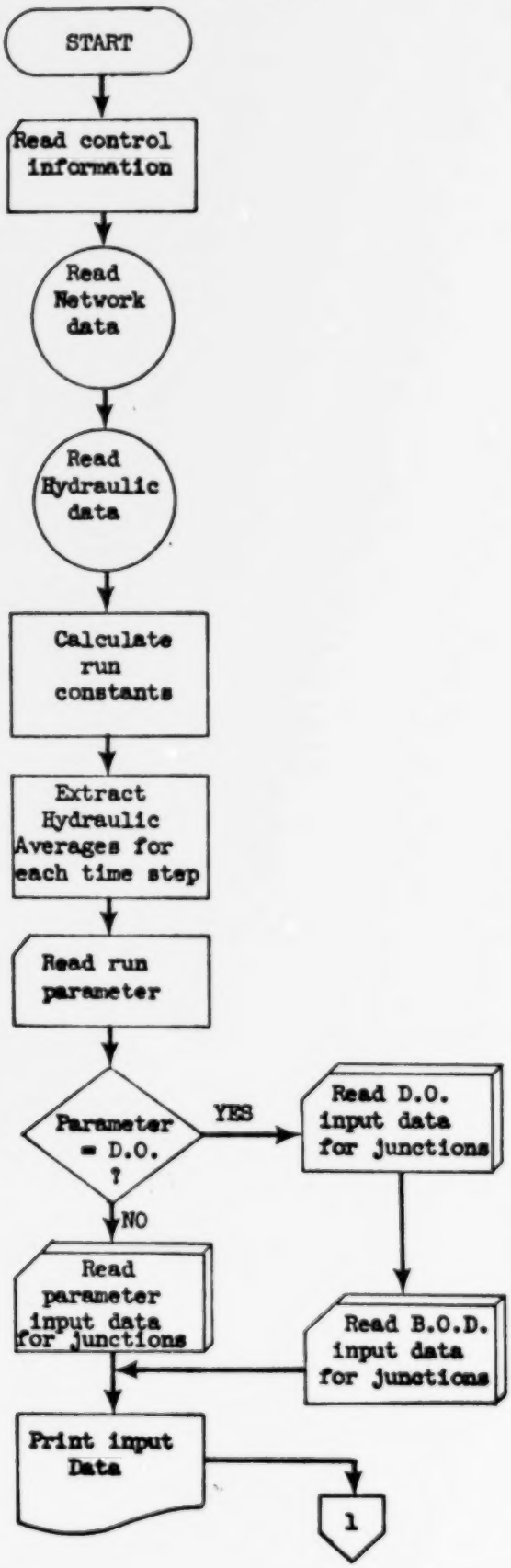
Logic Diagrams of Comprehensive Modeling System (CMS)

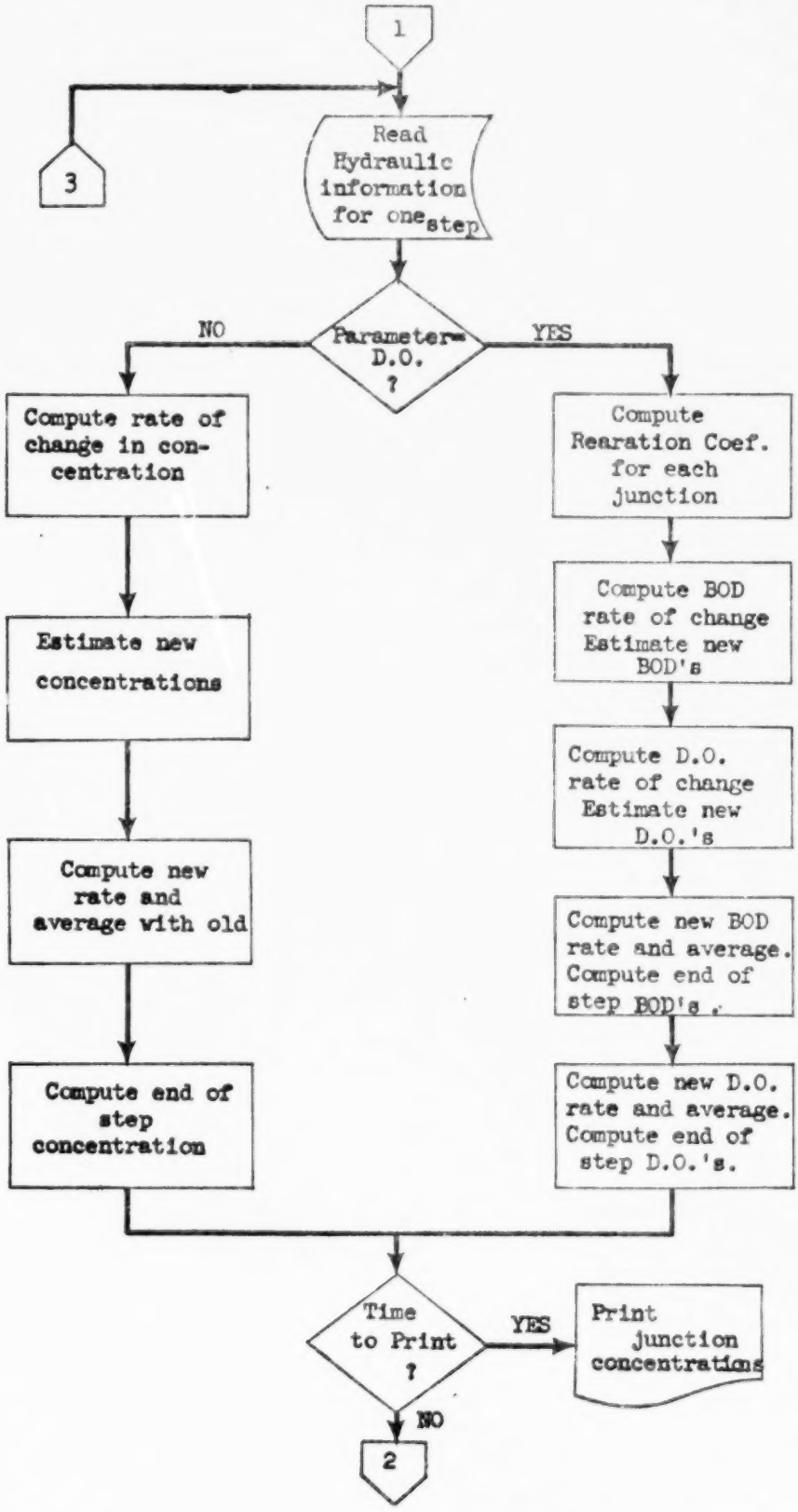
Unsteady Flow Program

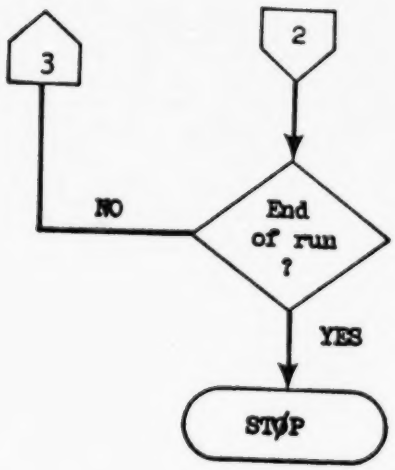



1
Initialize & Compute Constants
3
Compute Channel velocities & flows
Compute New heads from New flows
Compute New Channel Areas, Velocities & flows
Average old & new flows
Compute final heads from averaged flows
Update Channel depths & areas
Update junction surface areas
2

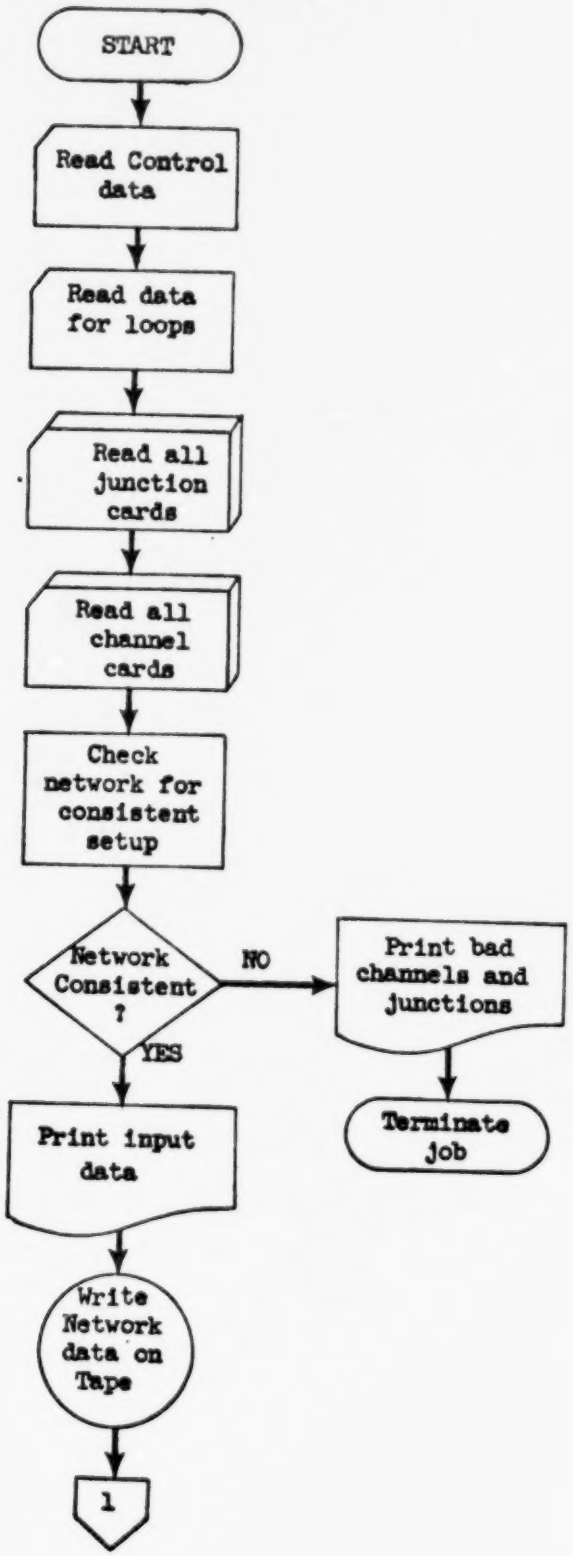

2
Time to write flow Tape ?
YES
Write flows and heads
NO
Time to collect for net flow ?
YES
Accumulate Heads, Velocities, flows
NO
3
Time to Print ?
YES
Print time, Heads, flows, Velocities
NO
YES
More Time left ?
Extract Net flows
Write Netflows, Average Heads and Velocity
Print Netflows Average Heads and Velocities
STOP

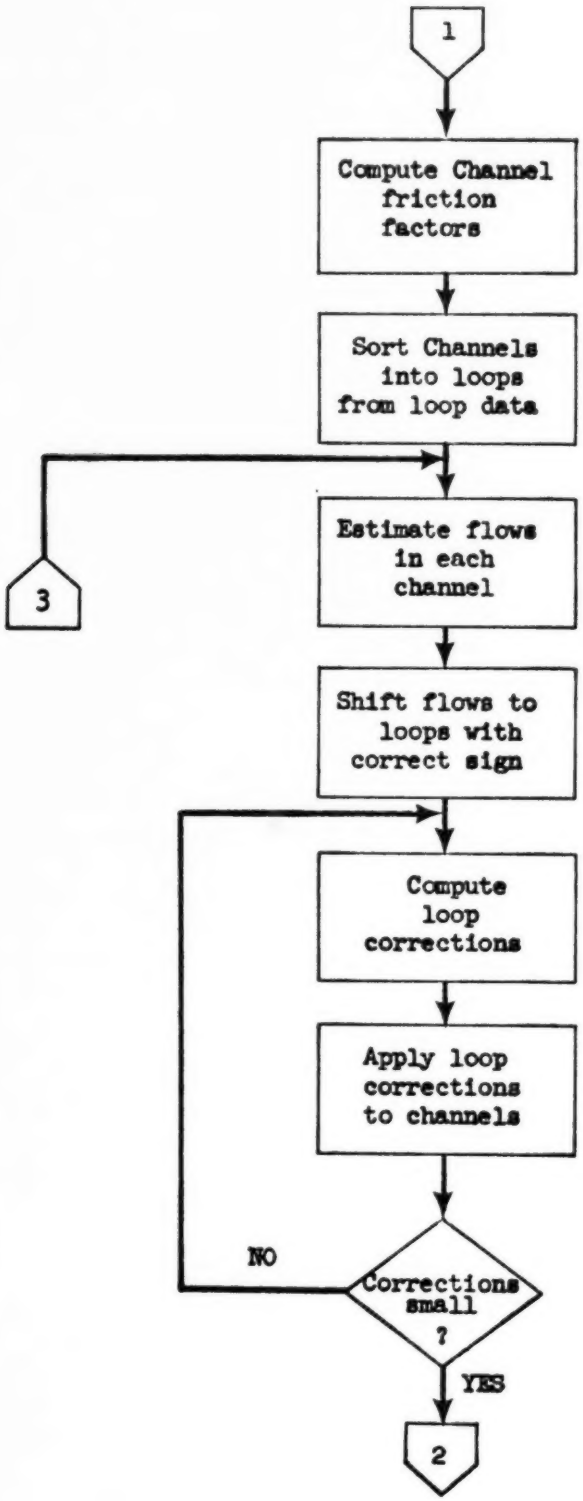

START
Read control information
Read Network data
Read Hydraulic data
Calculate run constants
Extract Hydraulic Averages for each time step
Read run parameter
Parameter = D.O. ?
YES
NO
Read D.O. input data for junctions
Read parameter input data for junctions
Read B.O.D. input data for junctions
Print input Data
1

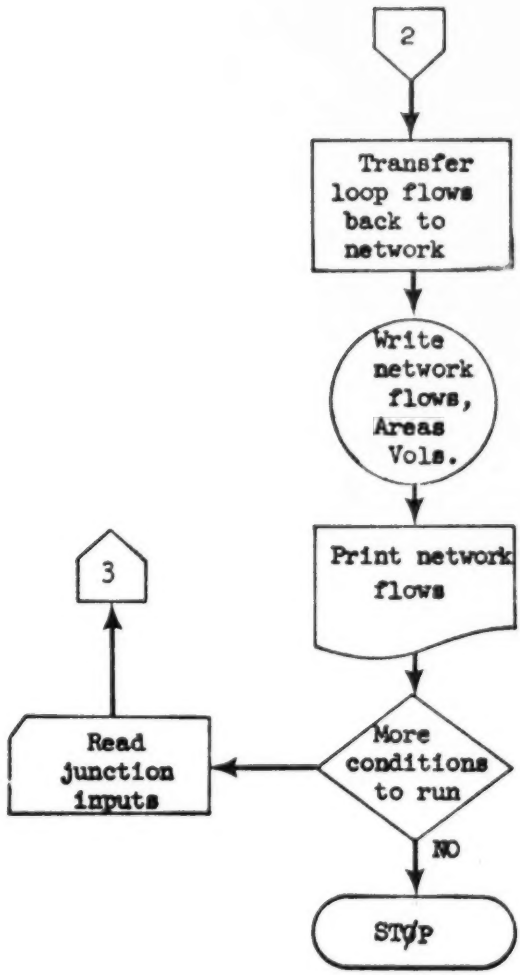

1
3
Read Hydraulic information for one step
Parameter= D.O. ?
NO
YES
Compute rate of change in concentration
Estimate new concentrations
Compute new rate and average with old
Compute end of step concentration
Compute Rearation Coef. for each junction
Compute BOD rate of change Estimate new BOD's
Compute D.O. rate of change Estimate new D.O.'s
Compute new BOD rate and average. Compute end of step BOD's.
Compute new D.O. rate and average. Compute end of step D.O.'s.
Time to Print ?
YES
Print junction concentrations
NO
2


3
2
NO
End
of run
?
YES
STOP

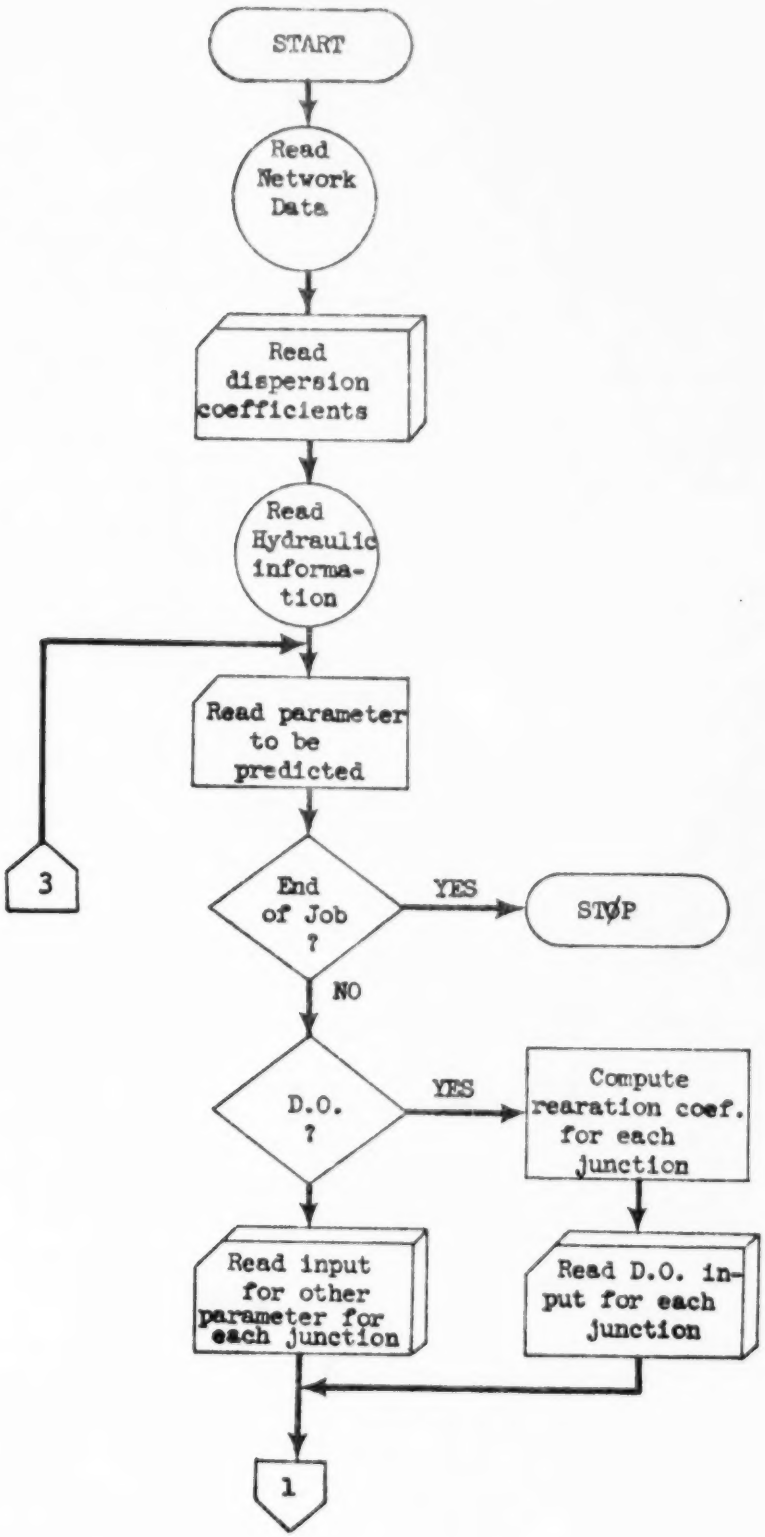
Steady Flow Program

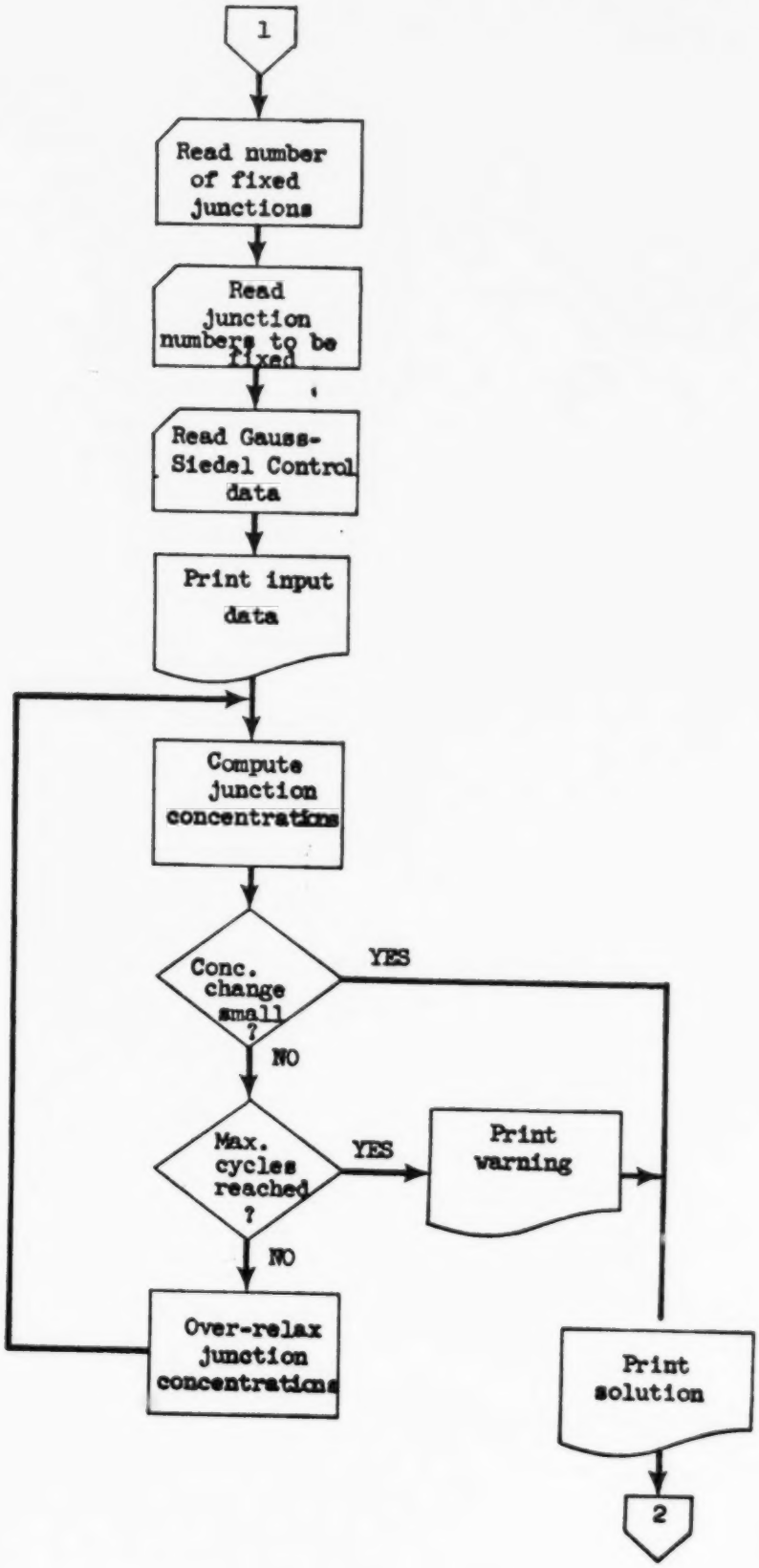


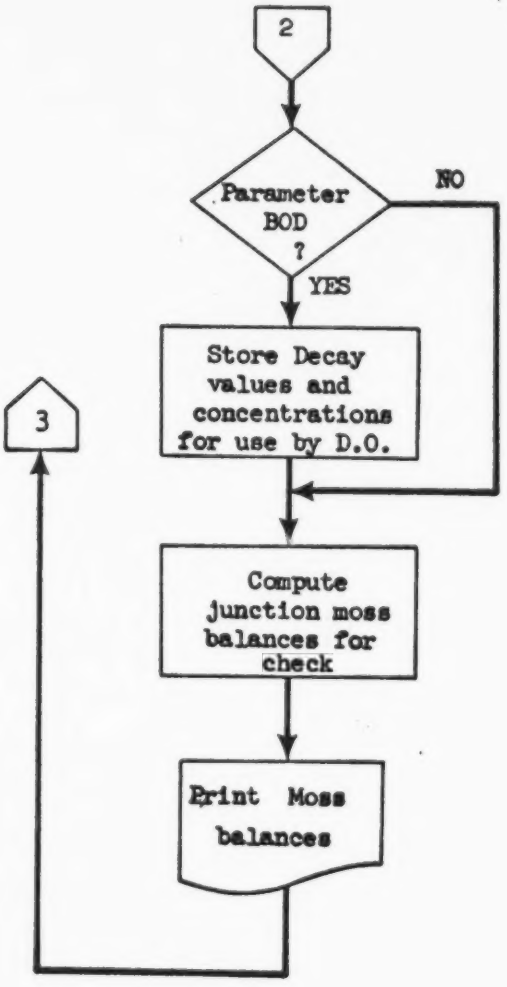

1
Compute Channel friction factors
Sort Channels into loops from loop data
3
Estimate flows in each channel
Shift flows to loops with correct sign
Compute loop corrections
Apply loop corrections to channels
NO
Corrections small ?
YES
2


2
Transfer loop flows back to network
Write network flows, Areas Vols.
Print network flows
More conditions to run
NO
STOP
Read junction inputs
3

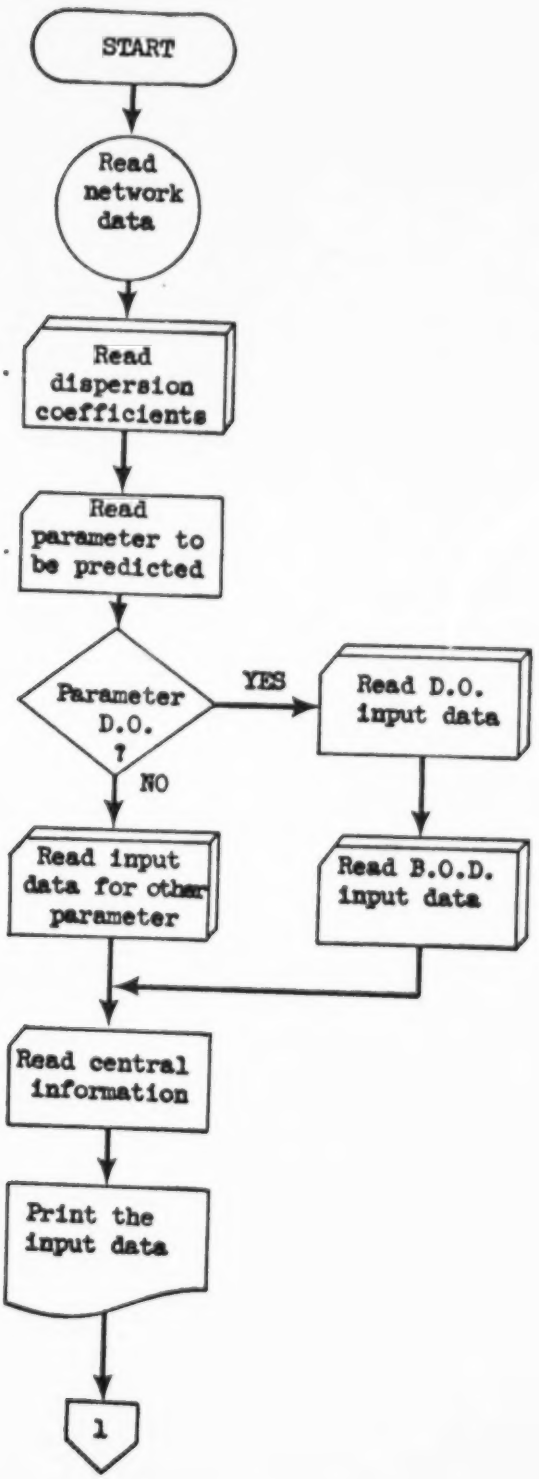
Steady State Quality Program

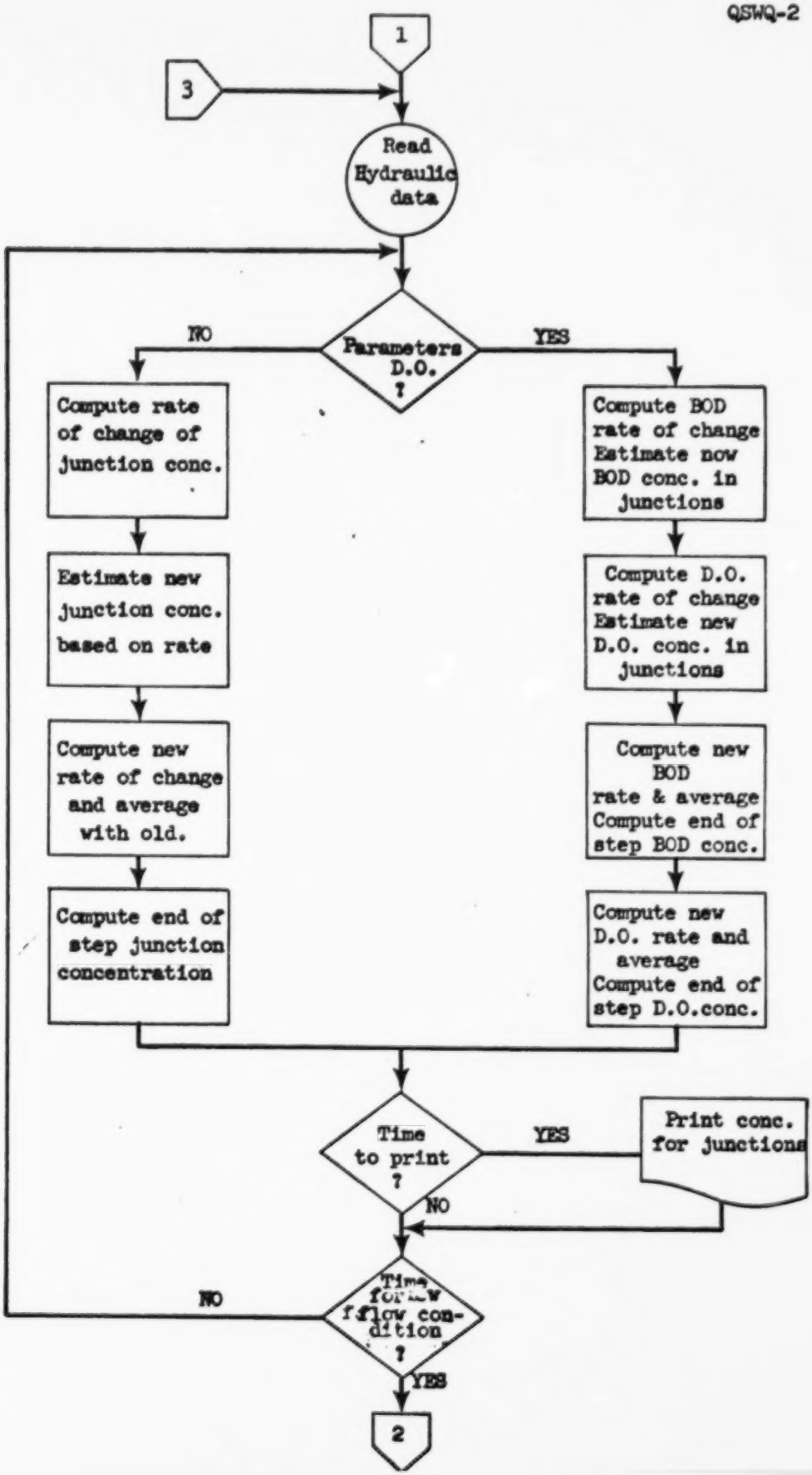


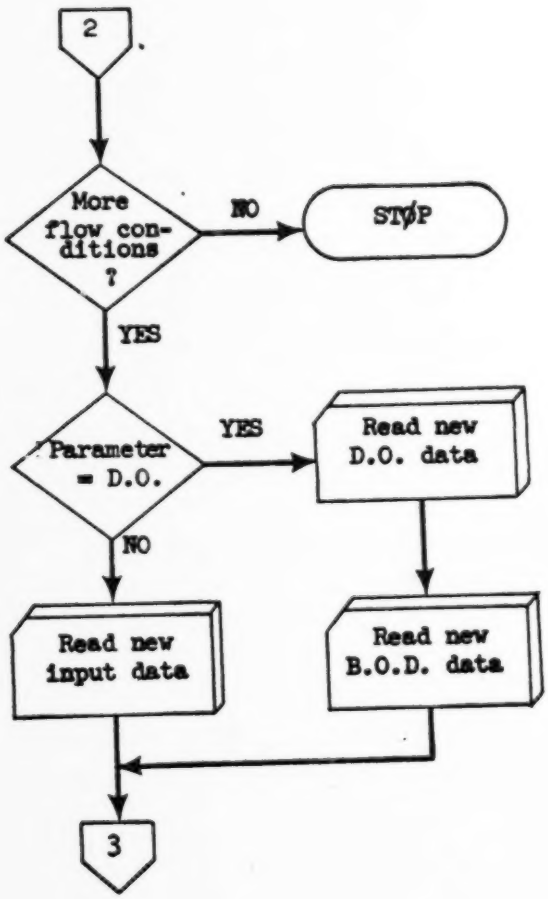

1
Read number of fixed junctions
Read junction numbers to be fixed
Read Gauss-Siedel Control data
Print input data
Compute junction concentrations
Conc. change small ?
YES
NO
Max. cycles reached ?
YES
Print warning
NO
Over-relax junction concentrations
Print solution
2


2
Parameter BOD ?
NO
YES
Store Decay values and concentrations for use by D.O.
3
Compute junction moss balances for check
Print Moss balances

Quasi - Steady Quality Program




1
3
Read Hydraulic data
Parameters D.O. ?
NO
YES
Compute rate of change of junction conc.
Estimate new junction conc. based on rate
Compute new rate of change and average with old.
Compute end of step junction concentration
Compute BOD rate of change Estimate now BOD conc. in junctions
Compute D.O. rate of change Estimate new D.O. conc. in junctions
Compute new BOD rate & average Compute end of step BOD conc.
Compute new D.O. rate and average Compute end of step D.O.conc.
Time to print ?
YES
Print conc. for junctions
NO
Time for new flow condition ?
NO
YES
2


2
More flow conditions ?
NO
STOP
YES
Parameter = D.O.
YES
Read new D.O. data
NO
Read new input data
Read new B.O.D. data
3